

RESEARCH ARTICLE

Does urbanization have positive or negative effects on Crab spider (Araneae: Thomisidae) diversity?

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ABSTRACT. Urbanization has a great impact on the diversity of living organisms. Spiders, for example, have been shown to respond negatively (some orb weaving species) and positively (ground dwelling species) to urbanization. The effects of urbanization on crab spiders (Thomisidae) (sit-and-wait predators that generally ambush their prey on flowers and leaves) are not sufficiently known. This paper describes the Thomisidae community that inhabits green patches in a temperate Neotropical city, Cordoba, Argentina, and its surroundings, and ascertains whether there are differences in species richness, abundance and composition between urban and exurban sites. Samples were collected from 30 sites during the summer and spring of 2013 and 2014, using the garden-vacuum method. We compared the abundance, richness and composition of Thomisidae among three habitat categories (urban, suburban and external). Seven species in three genera, *Misumenops*, *Wechselia* and *Tmarus*, were detected. *Misumenops* was the most abundant genus in Córdoba, and *Tmarus elongatus* Mello-Leitão, 1929 was collected in Argentina for the first time. The abundance, richness and composition of thomisid spiders did not differ between habitat categories, indicating that urbanization does not have a negative effect on the communities of these spiders in open green spaces. Site variability, on the other hand, does, suggesting that local factors may be more relevant than broad-scale factors to explain community patterns in this family.

KEY WORDS. Arachnid, biodiversity, city, richness, turn-over, urbanization.

INTRODUCTION

Thomisidae Sundevall, 1983, is a species-rich family of spiders comprising 175 genera and 2,153 valid species (World Spider Catalogue 2016). Species of this family can be distinguished from species of other families by the size of their first and second legs, which are longer and more corpulent than the third and fourth legs; their usually very colorful body (white, pink or bright yellow and also green); and their ability to walk sideways, very adroitly, which has granted them the nickname “crab spiders” (Foelix 2011). Thomisidae are often cryptically colorful, sit-and-wait predators that do not build capture webs (Benjamin et al. 2008) and generally ambush their prey on flowers and leaves (Jiménez-Valverde et al. 2010). Some species, when alone, display maternal care, for example *Diae*a Thorell, 1869, *Xysticus* C.L. Koch, 1835, and *Cymbachia* L. Koch, 1874

often enclose their egg-sacs with vegetation and remain with them until the eggs hatch. Individuals of *Diae*a, when in groups, display a different behavior, not observed in solitary crab spiders: they use four or more leaves to create an incipient nest where they lay and care for a single eggsac (Evans 1998).

Spiders are highly polyphagous predators that have the ability to store energy and go without food for long periods of time (Nyffeler and Breene 1990). Due to habitat preferences, several thomisid species such as *Misumena vatia* (Clerck, 1757), *Mecaphesa asperata* (Hentz, 1847) and *Misumenoides formosipes* (Walckenaer, 1837) spent most of their lives on flowers and mostly prey on pollinators (bees, true flies, bumblebees, etc.) (Morse 1981, Schmalhofer 1999). One such species, *Misumenops pallidus* (Keyserling, 1880), has the potential to become a pest control agent, since it preys on insect pests of crops (Cheli et al. 2006). In contrast, cursorial Thomisidae spiders such as *Xysticus* – a large

genus composed primarily of litter-dwelling species – spend more time in the ground litter than on flowers, and for this reason they prey less frequently on pollinators (Morse 1983). Aerial Thomisidae reach their ambush sites in a step-by-step process using several draglines and ballooning events (Benjamin et al. 2008), a capability that provides them high vagility, whereas the edaphic thomisid species have a limited cursorial capacity (Jiménez-Valverde et al. 2010).

Habitat alterations that result from urbanization affect the arthropod fauna (Philpott et al. 2014). As urbanization progresses, there are concomitant changes in the arthropod community patterns over time and across different habitats (McIntyre 2000). The changes in the composition of the community can involve two phenomena: “spatial turnover” and “species loss/gain”. Turnover implies the replacement of some species with others, as a consequence of environmental sorting or spatial and historical constraints, while loss/gain implies differences in species richness between assemblages (Baselga 2010, Ulrich and Almeida-Neto 2012). Several studies on spiders in green urban areas have found that spider abundance and richness increased in more developed areas, where there is more habitat disturbance (Philpott et al. 2014, Bolger et al. 2000). Magura et al. (2010) also found an overall higher richness in urban forest fragments compared to suburban or rural ones, although responses varied when considering species with different habitat affinities. Contrasting with those results, Shochat et al. (2004) found a reduction in spider diversity in disturbed areas within the Phoenix (state of Arizona), metropolitan area. Another scenario was found by Alaruikka et al. (2002), in 20 km urban-rural forest gradient in southern Finland, and Moorhead and Philpott (2013), in urban environment in Toledo, state of Ohio, who failed to find significant differences in spider richness between different kinds of disturbed habitats. In addition, the patterns of abundance and richness differ depending on the trophic and taxonomic group (Philpott et al. 2014). For example, orb-weaving spider communities may have low sensitivity to habitat fragmentation as a result of their generalist predatory behavior, their small size and their high capacity for dispersal (Nogueira and Pinto-Da-Rocha 2016). Thomisidae, and flower-spiders in particular, may show more specialized behavior when choosing their foraging sites and selecting their prey, as described for *Runcinioides argenteus* Mello-Leitão, 1929 from southeastern Brazil (Romero and Vasconcellos-Neto 2003) and for *M. pallidus*, following prey preference assays (Cheli et al. 2006).

The effects of urbanization on crab spiders have not been extensively studied. Here we surveyed the Thomisidae community dwelling in green patches in the city of Córdoba, Argentina, and its surroundings, to ascertain whether species composition, richness and abundances differ among urban, suburban and exurban sites. Since predatory species tend to be sensitive to anthropic processes, our working hypothesis was that

the community of sit-and-wait spiders would be influenced by the degree of urbanization and would differ. We also expected that species richness and abundance would increase from more intensely urbanized to more natural environments.

MATERIAL AND METHODS

Specimens were collected from green patches in the city of Córdoba (31°25'S, 64°11'W, 390 m.a.s.l.) Argentina. The study area is located within the Espinal ecoregion (Brown et al. 2006), a thorny deciduous shrubland forest that has been historically subjected to intense anthropogenic disturbance and modifications (including deforestation, urbanization and agriculture). Córdoba is a good example of a temperate city located within an agroecosystem environment with few remaining patches of natural forest. The sampling sites were defined as 2,500 m² areas located within green spaces that ranged from naturalized vegetation-forest remnants to small urban parks (1 ha).

Each sampling site was assigned to one of three categories of habitat, based on its relative location and characteristics of the land cover surrounding it within a 400 m radius buffer area (approximately 10 x 10 city block areas). The average number of houses per block and the percentage covered by impervious surface (buildings, road, etc.) were visually estimated from Google Earth images. Based on these variables, the following habitat categories were defined: 1) External patches: located outside the city limits, on natural or agroecosystems (but not within crops), with low impervious cover ($\leq 20\%$). 2) Suburban patches: located close to the city limits, suburban area (approximately 11 houses per block) with moderate proportion ($> 20 \leq 60\%$) of impervious surfaces. 3) Urban patches: located on the core of the city, with a high proportion ($\geq 70\%$) of impervious surfaces and highly built (22 houses per block on average). Twelve sites were urban, twelve were suburban and six were external (Fig. 1). External habitats were typically naturalized vegetation and/or forest remnants (Figs 2, 3) consisting mostly of secondary growth fragments of shrub vegetation, grasslands and trees (native and exotic) with low to moderate human intervention. Typical green spaces sampled in urban and suburban habitats were parks (Figs 4–7), consisting mostly of grassy areas with scattered trees and few shrubs, usually ornamental species, suffering from high (Figs 4, 6) to moderate (Figs 5, 7) human intervention.

Samples were collected using the Garden-Vacuum method to suck spiders from the vegetation, as described by Rubio and González (2010). Basically, a Stihl® vacuum cleaner with a 110 cm long and 12 cm wide tube was used to suck the vegetation in a square meter area during one minute (a “subsample”); subsamples were stored in ethanol 80% and spiders were sorted in the laboratory under a stereomicroscope. Collections were carried out once each month in November 2013 (springtime), February 2014 (summertime) and November 2014, to account for potential temporal variations in species presence or abundance.

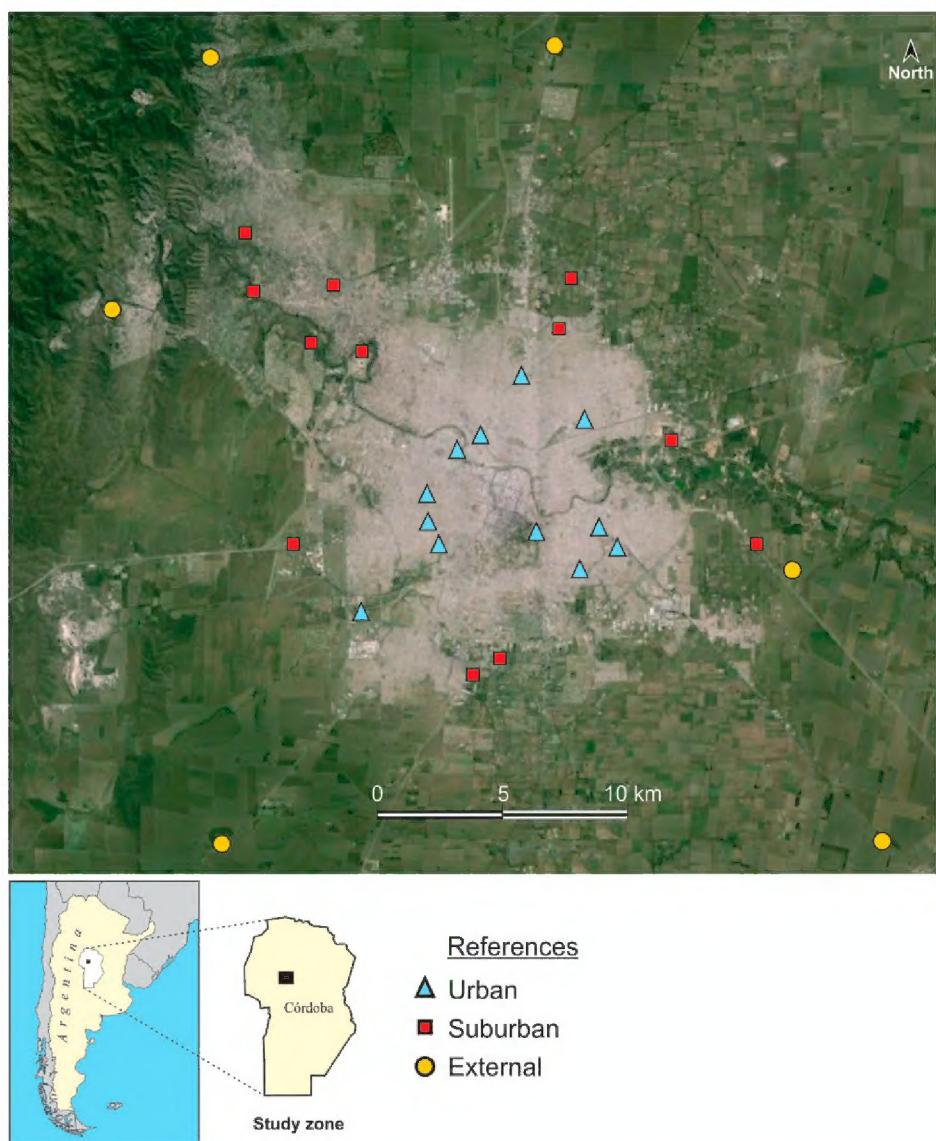


Figure 1. Location of sampling sites in Córdoba city, Argentina.

We avoided sampling in the winter since on a preliminary survey we had found that the abundance and richness of adult crab spiders, during that season, were much lower than in the summer and spring. On each site and sampling period we collected ten subsamples (5 at ground level and 5 up to 200 cm above the ground). Consequently, there were 30 subsamples per site (870 subsamples collected for all sites). A sample consisted of the total specimens collected from a site during the three sampling seasons (i.e., between November 2013 and November 2014). All Thomisidae collected were counted and adults were identified to genus or species (identifications by specialist Prof. Dr. Arno Antonio Lise and Prof. Dr. Renato Augusto Teixeira). Only adult specimens were included in the statistical analyses. Collecting permits were obtained from Córdoba province (Secretaría de Ambiente de la provincial de Córdoba, Dirección General de Recursos Naturales, Área de Gestión de Recursos Naturales) and from Córdoba city Municipality (Dirección de Espacios Verdes de la Ciudad de Córdoba). Vouchers specimens are stored in CREAN-IMBIV (CONICET-UNC).

To evaluate the completeness of the thomisid inventory, the sample coverage (Chao and Shen 2010), i.e. the total probability of occurrence of the species observed in the sample, was estimated for all sites and for the community from each patch category. For each site within a patch category, abundance and richness (observed and estimated with Chao-bc (Chao 2005)) were estimated, using SPADE software (Chao and Shen 2010). Patch categories were compared using “stats” library to run gen-



Figure 2–7. Details of typical sampling sites in Córdoba city, Argentina: (2–3) external sites; (4–5) suburban sites; (6–7) urban sites.

eral linear model and univariate analysis of variance followed by Tukey HSD tests ("agricolae" library) on R version 3.3.0 (R Development Core Team 2008). Abundance data (total species and *Misumenops*, the most abundant genus) were transformed to $\ln(x+1)$ to better fit a normal distribution. Since comparisons of diversity may be influenced by the diversity index chosen, we also plotted the Rényi index diversity profiles of communities, to explore robustness of diversity ordering using PAST version 3.11 (Hammer et al. 2001). The conservative criteria of non-overlap of the 95% confidence intervals were considered to assess significant differences between profiles.

The spatial turnover or change in the identities of species is a measure of the difference in species composition, either between two or more local assemblages, or between local and regional assemblages (Koleff et al. 2003). We used two indexes, Bray-Curtis and Simpson to compare the composition of species between "urban", "suburban" and "external" habitats. The first index considers abundance data while the latter is based on presence-absence data. Simpson index: $B_{SIM} = \min(b, c)/[\min(b, c) + a]$; where a = number of species shared between sites, b = total number of species that occur only in one site, and c = total number of species that occur in the other site. This index depends on a and on the relative magnitude of b and c , focusing on compositional differences rather than differences in species richness, thus it is recommended to measure turnover (Koleff et al. 2003).

Differences in species composition between the three habitat categories were assessed with the non-metric multidimensional scaling (NMDS), to ordinate spider diversity composition within different classes. Differences were corroborated with Analysis of Similarity (ANOSIM), a non-parametric test of significant differences between two or more groups (Clarke 1993), and 10000 permutations (PAST, Hammer et al. 2001).

RESULTS

In all, 298 mature and 1,505 immature individuals were collected. Mature specimens belonged to three genera, *Misumenops* Pickard-Cambridge, 1900, *Wechselia* Dahl, 1907 and *Tmarus* Simon, 1875. A total of five species were identified. One of them, very similar with *Tmarus digitatus* Mello-Leitão, 1929, was labeled as *affinis* since it needs further taxonomic confirmation. Additionally, there were three morphospecies. Since adult crab spiders (only immatures, 31 specimens) were not collected from one of the suburban sites, that site was excluded from further analyses. Table 1 displays the species, their abundances (by category and totally) and total incidence (percentage of sites where the species was found). Sample coverage was 1.00 for all specimens combined, 0.99 for urban, 0.98 for suburban and 1.00 for external sites, indicating that the samples obtained are a very good representation of the species richness in all categories (Table 2).

The average observed and estimated richness were similar, ranging from 2.33 to 3.1 and 2.5 to 3.5, respectively, and did not differ significantly between categories ($F_{2,26} = 0.65$, $p = 0.53$

Table 1. Composition, total number, and incidence (percentage number of sites a species was found) of Thomisidae species in green spaces in Córdoba city, Argentina.

Species	Urban	Suburban	External	Total	Incidence (%)*
<i>Misumenops maculissparsus</i>	106	65	19	190	89.7
<i>Misumenops pallidus</i>	21	16	7	44	67.0
<i>Misumenops</i> sp. 1	11	11	2	24	48.3
<i>Misumenops</i> sp. 2	5	4	2	11	31.0
<i>Misumenops</i> sp. 3	7	2	0	9	10.3
<i>Wechselia steinbachi</i>	1	2	5	8	17.2
<i>Tmarus elongates</i>	3	1	5	9	17.2
<i>Tmarus</i> aff. <i>digitatus</i>	2	1	0	3	6.9

*29 sites = 100%.

Table 2. Mean (\pm SD) estimates of Coverage, Observed richness, Chao1-bc and Abundances for each habitat category and total community.

	Urban	Suburban	External	Total
Coverage	0.99	0.98	1.00	1.00
Observed richness	3.00 ± 1.53	3.10 ± 1.37	2.33 ± 0.81	2.89 ± 0.25
Chao1-bc	3.37 ± 2.23	3.50 ± 1.70	2.50 ± 1.04	2.92 ± 0.33
Abundances	13.00 ± 10.36	9.27 ± 9.90	6.60 ± 3.90	10.28 ± 1.73

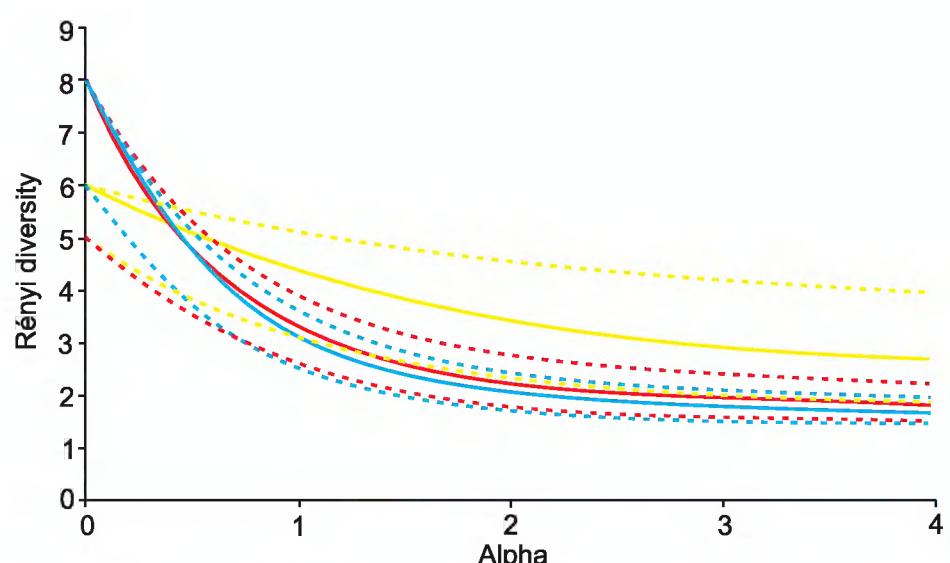


Figure 8. Diversity profiles from three habitat categories in Córdoba city, Argentina. Alpha values are represented on X axis and diversity values on Y axis. Urban, suburban and external categories are represented by solid cyan, red and orange lines, respectively and their 95% confidence intervals by dashed lines.

and $F_{2,26} = 0.62$, $p = 0.55$, respectively for observed and estimated richness). No statistical differences were detected either between patch categories in total average abundance ($F_{2,26} = 1.32$, $p = 0.29$; ranging from 6.6 to 13 specimens) (Table 2) or the abundance of *Misumenops* ($F_{2,26} = 2.19$, $p = 0.13$; ranging from 5 to 12.5 specimens). Consistently, there was a large overlap of the confidence intervals of the Rényi index diversity profiles of external and city (urban and suburban) habitats (Fig. 8)

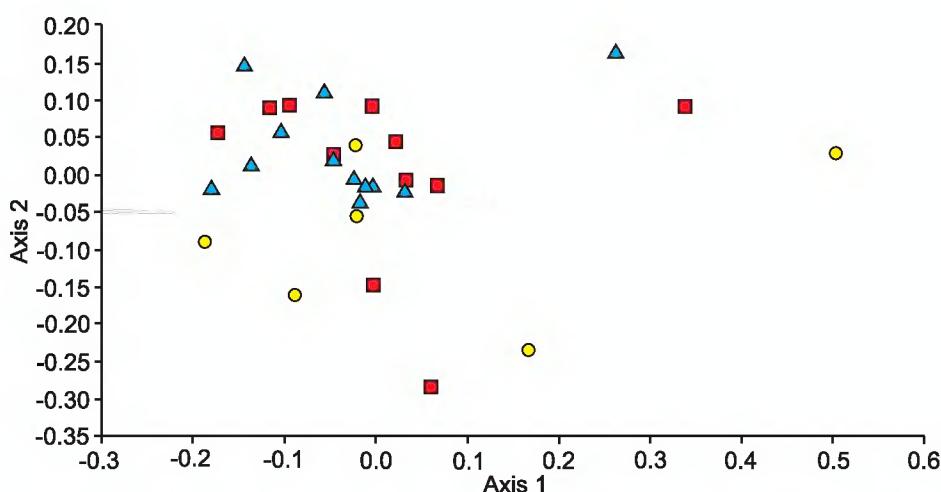


Figure 9. Non-Metric Multidimensional Scaling of three habitat categories (urban, suburban and external) in Córdoba city, Argentina. Bray-Curtis similarity index was used (two axes, stress = 0.16). Urban sites are represented by cyan triangles, suburban sites by red squares and external sites by orange circles.

The NMDS did not show clear discriminations among sites within categories; neither did the Simpson nor Bray-Curtis distances (only NMDS based on Bray-Curtis is shown for reference, Fig. 9). Consistently, no significant differences in species composition were detected either with ANOSIM ($p = 0.09$ for Simpson and probably a mild tendency for Bray-Curtis, $p = 0.059$) and there was no evident species turnover between categories.

Within each category, the Simpson index qualitatively indicated a comparably higher average species turnover than between categories (Simpson indexes were equal to zero), which was increasingly more evident from urban to external sites (urban = 0.2 (range 0-0.5); suburban = 0.23 (0-1); external = 0.57 (0-1)).

DISCUSSION

Species richness estimates and cover analysis indicated that the samples obtained, comprising seven species, provide an adequate representation of the Thomisidae fauna at all habitat categories. To our best knowledge, there are no published studies on urban Thomisidae from Argentina; however comparisons with other environments, using a combination of sampling strategies, show similar or lower richness values in Argentinian sites. From soya crops, Liljeström et al. (2002) collected 269 Thomisidae specimens (representing 47.2% of total spiders assembled) in four species-morphospecies. Armendano and González (2010) collected 2,012 specimens belonging to six morphospecies from alfalfa crops; Almada et al. (2012) gathered 1,051 specimens from cotton in the Santa Fe province, which they assigned to four species/morphospecies. In the Iberá provincial reserve (Corrientes province), 208 thomisids were collected belonging to six morphospecies (Avalos et al. 2009); while on degraded eastern Chaco forest of the same province, 149 spiders in 14 thomisid morphospecies were found (Avalos et al. 2007). Studies conducted on urban spiders in countries other

than Argentina report relatively fewer species of Thomisidae from green patches. For example, eight species were detected from dry and wet season samplings that combined nocturnal and manual collecting, beating trays and pitfall traps within a 500 ha urban coastal Atlantic Forest in Northeastern Brazil (Dias et al. 2006). On the other hand, Burkman and Gardiner (2014) sampled vacant lots, gardens and prairies in Cleveland, Ohio, for two years, finding only 226 thomisid individuals in one genus, *Xysticus*.

This is the first report of *Tmarus elongates* Mello-Leitão, 1929 in Argentina. Since the species had already been documented in neighboring Brazil (Mello-Leitão 1929), finding it in Argentina was not totally unexpected. It was found in 17% of the sites sampled in all three urbanization categories, with a relative abundance of 3%, being more abundant in external sites.

Misumenops was the most abundant genus in Córdoba, consistent with other studies on the spider communities of cotton (Almada et al. 2012) and alfalfa, where it was the most abundant in the herbaceous stratum (Armendano and González 2010). *Misumenops maculissparsus* (Keyserling, 1891) was the most abundant species in this study, accounting for 63.8% of the total adult specimens collected, and it was found in most (89.7%) sites, followed by *M. pallidus*, which represented 14.8% of the total number of (adult) specimens. By contrast, *Wechselia steinbachi* Dahl, 1907, *T. elongates* and *Tmarus* aff. *digitatus* were more frequently found in natural remnants compared to urbanized sites. These findings may indicate that species have different abilities to adapt to urban environments, but this hypothesis needs to be tested on a case by case.

The effect of urbanization is generally more evident in the core of a city, which is surrounded by areas of decreasing habitation and development with moderate or low disturbance levels (Kaltsas et al. 2014). Still, our results indicate that urbanization does not have a negative effect on crab spider species richness, at least in green spaces ≥ 1 ha, which is partly consistent with several studies showing higher spider richness in urban green spaces compared to less disturbed habitats such as Philpott et al. (2014). Studies on spider communities in Europe, however, found contrasting results. For example, Horváth et al. (2012) studied ground-dwelling spiders at an urban-suburban-rural forest gradient in Hungary and found higher richness in urban sites than in the other sites. Moreover, the results of Horváth et al. (2014) rejected a negative effect of urbanization on spider richness. However, Magura et al. (2010) cautioned about considering only overall diversity as an indicator of disturbance, since the responses of spider species may vary depending on their varied habitat affinities and disturbance tolerances; for example, overall richness may not vary if sensitive species are replaced with more generalist and/or tolerant species. In Debrecen, Hungary, they found that forest species were significantly affected by urbanization, while the populations of other generalist species increased in more disturbed patches. In Heraklion, Greece, Kaltsas et al. (2014) also observed an overall negative

effect of urbanization on gnaphosid richness and abundance, albeit not statistically supported, while indigenous species of these fast-moving, epigean nocturnal hunters were replaced by generalist species in the assemblages of urban areas.

The abundance of Thomisidae spiders, on average, was not affected by urbanization at the scale considered, neither was evenness in species abundances as inferred from the diversity profiles. These results differ from some studies that found a negative correlation between abundance and increased human disturbance, for example in Berkeley, USA (Fraser and Frankie 1986), but are consistent with others showing an inverse pattern such as Philpott et al. (2014) in Toledo, Ohio, USA. These differences may, in part, owe to dissimilarities between the habitats being compared. Fraser and Frankie (1986) surveyed very small green patches (57 to 73 m²) such as house backyards, which were not considered in Philpott et al. (2014) and our work, suggesting that there is a size threshold of probably about 1 ha, above which communities would not be affected by the size of the green patch. The bioclimatic characteristics of the region may also influence the effect of urbanization on spider communities, since both Córdoba and Toledo have wet summers, while Berkeley has dry summers.

A number of studies on spider assemblages in altered landscapes indicate that urbanization may affect diversity most noticeably in species composition (Gibb and Hochuli 2002, Schochat et al. 2004, Horváth et al. 2014). For example, a study based on pitfall collections along an urbanization gradient in Denmark showed the highest dissimilarity between urban and suburban sampling sites and the lowest between suburban and rural (Horváth et al. 2014). The highest similarities between assemblages were the within-habitat, which the authors interpreted as indicating assemblage stability. In contrast, we did not detect significant species turnover or replacement between the urban, suburban and external sites, indicating that urbanization did not affect the crab spider communities in green spaces at a large landscape scale. In fact, the species pool overlaps between the three environments. This could be explained by the great dispersal potential of these spiders (due to ballooning) and their broad environmental tolerance (Jiménez-Valverde and Lobo 2007). Since the region where Córdoba city is located has been historically subjected to intense anthropogenic disturbance and modifications, it is possible that the Thomisidae fauna remaining there is resilient to urbanization. Besides, smaller green patches not considered in this study, such as house gardens, may play a role in the step-by-step dispersal or even offer adequate niches for the species to subsist.

Greater differences between sites were found within the same habitat category, suggesting that local factors may be more relevant to explain community patterns. These results are consistent with Jiménez-Valverde and Lobo (2007), who highlighted that the establishment of spiders such as Thomisidae that have a great dispersal potential would depend on the physical structure of the environment, due to their life histories.

The presence of local scale factors limiting the establishment of species was also observed by Nogueira and Pinto-Da-Rocha (2016) in forest fragments in Brazil and Horváth et al. (2015) in unmanaged grasslands in Hungary, where plant structure (Nogueira and Pinto-Da-Rocha 2016) or plant cover, litter cover, bare ground cover, and patch size (Horváth et al. 2015) were the most influential on spider richness and density.

In conclusion, our results suggest that in a temperate city like Córdoba, the Thomisidae community of parks and other green spaces that are at least 1 ha are not negatively affected by urbanization. The effect of local factors such as vegetation structure should be assessed to better explain crab spider community patterns in cities and further understand the impact of environmental alterations on them. Also, future studies considering landscape composition and structure will contribute to a better understanding of the effects of urbanization on these spider communities and aid biodiversity conservation policies.

ACKNOWLEDGEMENTS

We specially thank Arno Antonio Lise and Renato Augusto Teixeira from Pontifícia Universidade Católica do Rio Grande do Sul, Brazil, for their assessment on the taxonomic identifications and Alejandro Barbeito for help with graphic design. We are grateful to three anonymous reviewers for their careful reading of our manuscript and for their constructive and insightful comments that helped improve our manuscript. The present study was partially supported by grants from SeCyT – UNC, PICT 2012-2014, and PIP CONICET, Argentina. R.M. Gleiser is a Career Researcher of CONICET; C.I. Argañaraz is a doctorate of FCEFyN, UNC and holds a scholarship from CONICET.

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Submitted: 13 September 2016

Received in revised form: 29 December 2016

Accepted: 13 January 2017

Editorial responsibility: Diego Astúa de Moraes

Author Contributions: RMG and CIA designed the study, collected and processed the samples, analyzed the data and wrote the paper.

Competing Interests: The authors have declared that no competing interests exist.